Advances in Cucumber Pickling

John L. Etchells, Ivan D. Jones, Thomas A. Bell

In this country the manufacture of cucumber pickles requires annually about 240,000 tons of pickling cucumbers. The crop is the fourth largest in acreage of the national truck crops (122,000 acres). A typical annual crop is about 10 million bushels and is valued at about 16 million dollars by 50,000 growers. About one-half the acreage is centered in Michigan and Wisconsin and one-fifth in the South Atlantic States.

The industry has three major operating fields. The first is manufacture of salt stock and genuine dills from green cucumbers by natural fermentation in brine. The second is the manufacture of such staple items as sweet, sour, and mixed pickles from the brine-cured cucumbers. The third is the pasteurization of various pickle products from green cucumbers, which is essentially a canning operation.

In each field, the industry has made notable advances in the past decade. Basic studies on the fermentation of salt stock have pointed out the complex nature of the microbial, chemical, and physical changes that take place. More information on how to spice pickles has made it possible to improve the finished products. Pasteurization has resulted in increased consumption of pickle products, by reaching new consumers and by giving packers a standardized procedure for preserving and maintaining the quality of their products. Storage problems have received renewed attention, and much that is advantageous has been learned. Many of these developments are the result of cooperative research by the Department of Agriculture and the North Carolina Agricultural Experiment Station.

The use of salt for the preservation of food began early in man's efforts to store edible material for his future consumption. During the years, salt preservation, or brining, has been gradually replaced by other methods, such as canning and freezing, for the bulk of commodities required for table use between seasons of production. Brining, however, is still used to produce cucumber pickles.

In times of national emergency, as during the Second World War, salt is used to preserve other vegetables, particularly when they cannot be frozen or canned because of wartime restrictions. During the period from 1942 to 1945, our research efforts turned to brine preservation of green beans, green peas, lima beans, wax beans, corn, lettuce, carrots, tomatoes, celery, okra, and certain leafy vegetables. Recommendations were given in a bulletin for the salting and brining of such vegetables for nonpickle use on both home and commercial scale. Information gathered during the 1943 season showed that several million pounds of vegetables such as corn, green peas, green beans, celery, and okra were successfully salt-preserved by commercial concerns for use in food products. Substantial amounts were also preserved in the home by this method.

In the cucumber-pickling industry, brine salinity is usually recorded in terms of degrees salometer, as measured by a hydrometer calibrated in percentages of saturation with respect to sodium chloride (0° to 100° sal.). For the convenience of the reader, degrees

salometer have been converted to the approximate equivalent in percentage of salt by weight (for example, 20°, 30°, and 40° sal. brines would approximate brines with 5, 8, and 10 percent of salt).

Cucumbers are brined in wooden vats ranging in capacity from 200 to 1,200 bushels. In the South, where fermentation is relatively rapid, the vats are filled with green cucumbers, either graded to size or mixed, and fitted with loosely constructed wooden board covers keyed down firmly with wooden 2 by 4's or 4 by 4's. Salt brine of suitable concentration is added to a level of a few inches above the cover in each vat. Next, dry salt is added on the cover of the vat to maintain the initial brine concentration, which otherwise would be diluted by the water in the cucumbers. The initial concentration ranges from 8 to 10 percent salt, depending on the individual pickling plant. Usually the brine strength is gradually raised by adding enough dry salt on the cover to give a holding strength of 16 to 18 percent at the end of 4 to 6 weeks. Under these conditions and with brine temperatures of 75° to 80° F., salt-tolerant micro-organisms grow for at least 4 months. The micro-organisms that cause the fermentation come from the cucumbers and adhering particles of soil. They use as food the soluble nutritive material, principally sugar, that diffuses into the brine from the cucumber as the result of the action of salt solution on the tissue.

The growth of the micro-organisms, or fermentation, produces lactic and acetic acids, alcohols, and gases. The type of fermentation, with respect to the microbial groups involved and the end products formed, is greatly influenced by the starting brine strength and by the rate at which it is increased. At the end of the curing process, about 3 months, the cucumbers have changed from a green, opaque, buoyant fruit to olive-colored, translucent, gas-free salt stock.

In the North, the brining procedure is different. There the intake of cucumbers is slower, and therefore the vats are not filled so rapidly as in the South. The salting method, usually a combination of brining and dry salting, consists of adding a few inches of brine as a cushion in the vat and gradually filling the vat with cucumbers and dry salt. Some of the brine is formed by action of dry salt on the cucumbers. The initial brine strength used is usually in the range of 6 to 7.5 percent and is not generally raised according to any set schedule but is dependent mostly on temperature conditions and progress of the acid fermentation. The aim is to have the stock cure out as much as possible before cold weather—otherwise, vigorous gaseous fermentation takes place in the spring as the brine warms up. Another feature characteristic of northern brining stations is that most of the vats are sheltered. Shelters, which range from high sheds to enclosed buildings, prevent the dilution of the brine by rain or snow, but provide ideal conditions for the film-forming yeasts, which are absent from the brine surfaces of vats in the open and exposed to direct sunlight.

During the natural fermentation of cucumbers for salt stock, the following salt-tolerant microbial groups may be present: Acid-forming bacteria, yeasts, coliform bacteria (*Aerobacter*), and obligate halophilic (salt-loving) bacteria. As a result of the growth of these organisms, lactic and acetic acids, alcohol, and gases are formed.

UNDER SUITABLE CONDITIONS as to temperature and brine strength, an active acid fermentation, resulting from the growth of salt-tolerant, acid-forming bacteria, begins within a day or so after the cucumbers are brined and continues for 4 to 6 weeks. The preserving effect of the brine is due chiefly to the combined action of the salt and the developed acidity. There is a direct relationship between numbers of lactic acid bacteria and the brine strength used. For example, in 5-percent brines upward of 200 million bacteria per milliliter are found. Cor-

respondingly smaller populations are found as salt concentrations increase. At 15 percent concentration or stronger, little or no growth by the acid-producing bacteria is observed. The effect of salt on the growth of these organisms is shown by the degree of developed acidity. Fermentations at salt concentrations of 5, 10, and 15 percent result in decreasing brine acidity—0.7, 0.4, and 0.1 percent total acid calculated as lactic.

Identification studies on cultures of lactic acid bacteria from commercial fermentations at 5, 8, and 10.5 percent salt showed that the bacteria were *Lactobacillus plantarum.* Additional cultures from commercial brines at 11 to 12.5 percent salt were also identified as this species.

Yeasts associated with the cucumber brines are of two general groups: Those that produce a gaseous fermentation in the brine; and those that produce luxuriant films on the brines exposed to air but sheltered from direct sunlight. The two groups are frequently confused in the reports on cucumber pickling.

Yeasts capable of gaseous fermentation have a high tolerance to salt and acid. Fermentations are found in brines ranging from 2.5 to 20 percent salt by weight. As a rule, the salt content governs the time yeast growth starts, as well as the duration of activity. Carbon dioxide is evolved from the brine surface as long as yeasts are present. At brine temperatures of 75° to 80° F. and fermentations at 5 percent salt strength, yeast growth usually starts within 2 to 3 days and populations drop sharply after 7 days of activity. At 10 and 15 percent brine strengths, yeasts start growing in 7 to 12 days, respectively, and the gaseous fermentation continues for a much longer period than at 5 percent. The reason for the more active development in the stronger brines is that the lactic acid bacteria are inhibited as the brine strength is increased and more fermentable material remains for the yeasts, which are not similarly inhibited.

The principal subsurface yeasts, isolated and identified during fermentation of 42 commercial vats of cucumbers at two plants, fell into the following six genera in the order of frequency of isolation: *Torulopsis,* 721 cultures; *Brettanomyces,* 588; *Zygosaccharomyces,* 59; *Hansenula,* 49; *Torulaspora,* 6; and *Kloeckera,* 1. Two new species, *Torulopsis caroliniana* and *Brettanomyces versatilis,* accounted for 88 percent of the total cultures. These results are based on fermentations under southern conditions. First results in studies on cultures obtained from northern brines indicate that yeast activity also forms part of the general fermentation of cucumbers brined in Michigan, Indiana, and Wisconsin. Several of the species—*Torulopsis caroliniana, Brettanomyces versatilis, Hansenula subpelliculosa, Torulaspora rosei,* and *Zygosaccharomyces* spp.—were found in both brining areas.

Film-forming yeasts do not depend on sugar for growth but use organic acids or alcohol in the brine as a source of energy. Their growth causes a decrease in brine acidity. In 1939, E. M. Mrak and Lee Bonar, of the University of California, found that the surface films on seven samples of cucumber salt stock at 18 to 20 percent salt were the result of growth by film-forming yeasts belonging to the genus *Debaryomyces.* However, films on seven samples of dill-pickle brines at 4 to 6 percent of salt were identified as species of the genera *Mycoderma* and *Picha.* Work by the writers shows that species of *Endomycopsis, Candida,* and *Zygosaccharomyces,* in addition to *Debaryomyces,* produce films on commercial cucumber brines.

A third type of fermentation frequently takes place during salt-stock production. This fermentation is characterized by the evolution of hydrogen. Bubbles of this gas forming on the brine surface may be exploded by ignition with a flame, thereby giving a ready practical test for this type of fermentation. Hydrogen fermentation in the cucumber brines is caused by two

groups of bacteria and the gas formed is a mixture of carbon dioxide and hydrogen. One group has been established as belonging to the genus *Aerobacter*. The other, unidentified, is closely related, but differs in that at least 5 percent salt by weight is required before it will grow. Both groups are very salt-tolerant, but also very sensitive to the acid produced by the acid-forming bacteria and to added organic acids, such as vinegar and lactic acid. This sensitivity to acid stops the hydrogen fermentation in the 5 percent salt range owing to the simultaneous rapid growth of acid-forming bacteria. In certain seasons, however, these organisms seem to predominate on the cucumber, and 10.5- and 15-percent brines develop gaseous fermentations that are very vigorous to violent.

The lack of sufficient oxygen and the salt content of the brine are factors that discourage the growth of molds beneath the brine surface. Molds are usually present at the start of brining, but decrease rapidly and disappear within a few days. Under sheltered conditions, molds may be found growing along with film yeasts. But molds have appeared on the surface of brines even under outside conditions during periods of cloudy and humid weather. In experiments with cucumbers at 10.5-percent brine, and wax beans at 4-percent brine, unrestricted mold growth softened the vegetables to the extent that they were not usable.

Salt-stock spoilage is of two kinds. One is the formation of "bloaters," or hollow cucumbers, as a result of gaseous fermentation; the other is softening of the stock, which is attributed to pectin-splitting enzymes.

Bloater formation may be of either the "balloon" or the "lens" type. In the balloon type, the carpels of the cucumber separate because of internal gas pressure and are pressed flat toward the skin, leaving a large gas- or liquid-filled cavity. In the lens type the gas pockets in the cucumber tissue are smaller and lens-shaped. Lens bloaters are generally restricted to the smaller cucumbers. Leaders of the industry estimate the loss due to bloaters at $750,000 annually. This loss actually is in the reduced value of the cured stock, because bloaters cannot be used as whole pickles but only as cut pickle or relish. Although gaseous fermentation by yeasts is responsible for most of the bloaters, sporadic hydrogen fermentation also contributes to bloater formation. Hydrogen fermentation may affect cucumbers of any size; yeast fermentation, however, usually turns only the larger ones into bloaters. The influence of the initial brine strength on the percentage of bloaters in the large cucumbers is shown by averaged results from 28 vats over a 4-year period: At brine strengths of 5, 10.5, and 15 percent salt, the percentages of bloaters formed were 6.5, 22.9, and 43.6.

Softening of salt stock by pectin-splitting enzymes does not result in yearly losses like those due to bloaters, but may be more severe in some years than others, and in some brining areas than in others. This condition may develop at plants using different brining treatments and different varieties of stock and with vats either outside or inside. In other words, softening may sometimes be widespread and take place under varied conditions of plant procedure. The softening may be only slightly noticeable or it can progress rather rapidly so that the stock cannot be used because of lack of firmness.

To date there has been no clear-cut demonstration that any one group of micro-organisms is responsible for the softening of salt stock in commercial cucumber fermentations. A large number of organisms, including different genera of bacteria, yeasts, and molds, have been reported as capable of producing the pectin-splitting enzymes that would destroy cucumber tissue.

Whether one or more of these groups could develop in brines would depend on the adaptation of certain strains to salt tolerance.

We have approached this softening problem from the standpoint of detection of the specific softening enzyme in

the brine. We have learned that a pectin-destroying enzyme corresponding in chemical behavior to commercial pectinase is responsible for the loss in firmness of salt stock and have made progress in correlating pectinase activity of the suspicious brines with the degree of softness of the salt stock. We are using this approach also in determining pectinase activity of the different groups of the organisms isolated from the fermentations.

So far, a total of 143 yeasts, representing 66 species in 15 genera, have been screened for their ability to produce the salt-stock softening enzyme. This total included representative species of yeasts responsible for the gaseous fermentation of brined cucumbers, as well as those responsible for film formation on brines. Thirty-three of the species tested came from other collections. None of the yeasts from cucumber brines was found to be a potential source of the softening enzyme (pectinase). However, most of the film-forming species were capable of changing pectin to pectic acid. Four yeasts from sources other than cucumber brines were able to produce the softening enzyme.

The cucumber plant and its fruit have also been studied as a possible source of the salt-stock softening enzyme. An enzyme very similar to that responsible for softening of brined cucumbers has been found in dry cucumber seeds, male flowers, fertilized female flowers, and also in the ripe cucumbers. A second enzyme, known as pectase, has been found in various parts of the cucumber plant and the fruit. Working alone, this enzyme probably would not damage the cucumber as far as firmness is concerned.

However, pectase is important because it has the property of speeding up the action of the softening enzyme (pectinase). During the growth of a cucumber, from a very small fruit to maturity, the enzyme pectase remains at a rather constant level. This is in sharp contrast to the tomato where the enzyme content increases rapidly as the fruit ripens. Our enzyme studies demonstrate that the cucumber itself may be an important contributing factor to the spoilage of salt stock resulting from softening.

VARIOUS TYPES OF finished pickle products are made from completely cured salt stock by a series of operations—leaching out most of the salt, souring with vinegar, and sweetening with sugar.

The leaching, or desalting, operation is called processing by the industry. The 15 to 18 percent of salt in the cured stock is reduced to about 4 percent by at least two changes of water. In the last change the water is heated to about 130° F. and turmeric is added for coloring and alum for crisping or firming. After desalting, the stock is covered with distilled vinegar. This is referred to as souring. Sour pickles and processed dills are made directly from the souring operation and are made to contain about 2.0 and 0.8 percent acetic acid, respectively.

The sweetening operation is usually carried out in small tanks of 40- to 100-bushel capacity, although some packers prefer to sweeten in barrels. To make sweet pickles, the processed stock, after souring in distilled vinegar, is covered with liquor, or sirup which contains all the vinegar and some of the sugar to be used. The remaining sugar is added gradually until the desired sweetness is reached; otherwise the pickles will shrivel badly.

No legal requirements have been set for the sugar content of sweet pickles. From the manufacturing standpoint, enough vinegar and sugar must be added to prohibit fermentation.

The sugar content of the commercially made pickles may vary from 36 to 51 percent (20° to 28° Baumé) and the acid content from 1.6 to 2.1 percent acetic acid (16 to 21 grains vinegar). As the sugar content is increased, less acid is required for preservation. For example, a product finished at 51 percent sugar would require at least 1.6 percent acetic acid, as compared to

one finished at 36 percent sugar, which would require at least 2.1 percent acetic acid. To prevent fermentation, sweet pickles containing less than 2.0 percent acetic and 36 percent sugar are pasteurized according to the procedure described later.

Proper blending of the spices is important in the preparation of pickles. Commercial formulas vary, depending on the product, the individual manufacturer, and customers' preferences. The common whole spices used are allspice, cloves, coriander seed, yellow mustard seed, celery seed, cardamon seed, dillweed seed, ginger root, bay leaves, cassia, mace, Japan chilies, and black pepper. In the past 10 years rapid development has been made in the use of spice oils and oleoresins as replacements for whole spices in some pickle products. F. W. Fabian, of Michigan State College, who provided this list of spices, has contributed much to the knowledge of spicing pickles with such oils as clove, cassia, allspice, or pimento, in combination with the oils of nutmeg, ginger, thyme, and cardamon.

YEASTS AND LACTIC ACID BACTERIA usually will grow in finished sweet pickles that do not have sufficiently high levels of sugar and vinegar. The growth of yeasts in jars of whole sweets imparts a "fermented" taste and usually causes bloaters. Yeast fermentation may also develop during the sweetening process in tanks if the acetic acid content drops below 2.0 percent, causing bloater formation if it goes far enough. Molds and film yeasts may develop on the liquor surface of pickles, including sours and dills, chiefly as the result of faulty jar closure. Too much head space in low-acid products, such as dills made from salt stock, may result in the growth of film-forming yeasts.

Plant sanitation is important in connection with spoilage problems. Yeasts can develop high tolerance to acid or sugar or both when their growth is unrestricted by lack of cleanliness in a plant. In a recent outbreak of spoilage of finished pickle products, we isolated an acid-tolerant yeast belonging to the genus *Zygosaccharomyces*. Under laboratory conditions, this yeast was capable of fermenting liquors containing various amounts of acid, sugar, and benzoate of soda. Three solutions containing the following ingredients were fermented: (1) 10 percent sugar and 3.0 percent acetic acid; (2) 10 percent sugar, 1.5 percent acetic acid, and 0.1 percent benzoate of soda; (3) 60 percent sugar.

PASTEURIZATION rapidly has become of major importance. It is estimated that at least 20 percent of the domestic crop of pickling cucumbers now goes into fresh pasteurized products. Pasteurization has made it possible to add a new line of products to the standard sweets, sours, mixed pickle, and relish. The characteristic crispness and fresh appearance and flavor of the pasteurized fresh dills and fresh sweet slices make them popular with consumers. The moderate requirements of sugar, vinegar, and spices in their manufacture make them popular with packers, too.

Probably a dozen or more types of pickles made from fresh or partially fermented cucumbers require pasteurization. These products may be classed as fresh or unfermented, partly fermented, or fully fermented. Pasteurization is required for the first group to prevent fermentation, for the second to stop the fermentation under way, and for the third to prevent the further growth of organisms or the action of fermentation byproducts that might reduce the firmness of the pickle during storage.

No doubt the bulk of the pasteurized pack is composed of the sliced fresh cucumber pickle, commonly called bread-and-butter pickle, and the fresh dill pickle. A number of closely related types of dills that require pasteurization should be mentioned. These differ chiefly in the duration of the natural fermentation period allowed before packaging, or in the amount of acid,

salt, and spices used during preparation. Quite often, partly fermented dills are referred to as Polish, Hungarian, overnight, or fresh-fermented dill pickles. The addition of garlic and more spicing may be sufficient reason for the packer to label any one of the various types of dills a kosher-style product. Ordinarily such a pickle is relatively low in acid and salt and is rather highly seasoned, particularly with garlic.

Genuine dills, when properly pasteurized, retain most of their firmness over a storage period of many months. Loss of firmness in genuine dills either before or after marketing has been an important reason for the marked reduction in their manufacture. Even though the problem of retaining the firmness after packing has been solved by pasteurization, sales resistance has developed because of the milky brine, which is the result of the activity of the organisms of the natural fermentation. The customer has been sold on substitutes in the form of processed dills from salt stock which have clear brines. A genuine dill with an added clear brine is not the answer, because the original flavor produced by the fermentation is changed and the cost of fermenting the dills in barrels or tanks exceeds that for substitute products.

Pasteurization is also required for the sweet pickle made from salt stock, which differs from the usual sweet pickle in that it lacks enough sugar and vinegar to prevent fermentation.

The pasteurization treatment has been developed for the industry by carefully conducted experiments under commercial conditions to determine the correct amount of heat required to kill the organisms responsible for spoilage, yet retain most of the characteristic appearance and crispness of the fresh cucumber tissue. On the basis of this work, a procedure involving the use of a maximum product-interior temperature of 165° F., followed by prompt cooling, has been recommended for pasteurized pickle products containing required amounts of vinegar. The process is adaptable for both continuous and batch pasteurizing operations.

Spoilage occurs in products of this class when they are improperly pasteurized, and is caused chiefly by yeasts or acid-forming bacteria, or both, that survive faulty heat treatment. Molds and film yeasts are spoilage factors in cases of poor jar closure. Excessive heating of pasteurized products gives them a cooked flavor and soft texture.

CUCUMBER VARIETIES used in pickling may be divided into two general groups—white-spined varieties and black-spined varieties. Most of the pickles manufactured commercially are made from black-spined varieties. We have recently shown that the quality of salt-stock cucumbers and manufactured pickle products is closely related to the variety of cucumber used. Such factors as shape, crispness, skin color, skin toughness, and the presence of bitter flavors account for the differences between varieties.

A number of white-spined varieties have recently been developed for use in pickling. Several have certain advantages over black-spined cucumbers. For example, some are more productive, ship better, and can be held in temporary storage as fresh stock with less spoilage than can black-spined varieties. However, the type or variety of cucumber best suited to an individual pickling company depends on the location of the processing plant, the type of product being manufactured, and customers' preferences.

THE ULTIMATE OBJECTIVE of any changes in cucumber pickling is to place this industry among the controlled-fermentation industries. Clearer understanding of fermentation and identification of increasing numbers of microbial groups and their byproducts contributing to the fermentation bring the controlled-fermentation goal closer. Control procedures cannot be developed until the basic information is col-

lected and understood. Practically the only control the packer has today is the use of salt. Actually, salt has no effect on some micro-organisms that cause difficulty, and may actually foster their growth. Numerous experiments on a commercial and semicommercial scale have definitely proved that no one brining treatment is capable of giving the same degree of firmness of stock consistently from one year to another.

Pasteurization, with its new line of pickle products, has been a notable advance in the industry. The practice will undoubtedly continue to increase.

In the past decade there has been a marked increase in the number of technically trained employees and a decided improvement in laboratory facilities at pickling plants. With a better knowledge of chemistry, bacteriology, engineering, and food processing, packers can develop more standardized procedures that will result in improved quality of products, reduction of spoilage, and better sanitation.

JOHN L. ETCHELLS *is in charge of the food-fermentation investigations of the Bureau of Agricultural and Industrial Chemistry. He is a native of Michigan and received his doctorate at Michigan State College. Since entering the Department in 1935, he has been engaged in research relating to the bacteriological changes during the fermentation of brined and salted vegetables, especially cucumbers.*

IVAN D. JONES *is research professor of horticulture, in charge of fruit and vegetable processing at North Carolina State College of Agriculture and Engineering. For the past 15 years he has been engaged in research covering a wide field of problems dealing with the cucumber-pickling industry. He received his doctorate in agricultural biochemistry at the University of Minnesota.*

THOMAS A. BELL *is a native of South Carolina and a graduate of Wofford College and North Carolina State College of Agriculture and Engineering. He is a chemist in the Bureau of Agricultural and Industrial Chemistry and since 1940 has done research on chemical changes in brined vegetable fermentations.*

ACCEPTANCE of the results of advancement in science is sometimes delayed. Take vitamin A. Investigators in Wisconsin demonstrated that there seemed to be an association of the vitamin A potency of food with yellow color. Investigators in Missouri, however, had shown that color is not necessarily associated with the vitamin A in eggs. It took some years and the discovery of yellow carotene as a precursor of vitamin A to discover the reason for the discrepancy. Vitamin A is practically colorless, but carotene is one of the yellow pigments of plants, milk, and milk fat—but not of egg yolk.

The association of yellow color with the presence of carotene in green leaves has been one of the most practical discoveries made in nutrition for popular education in the feeding of both man and animals. It leads, in part, to the designation "leafy green and yellow vegetables" as an important group of foods.—*Paul E. Howe, Bureau of Animal Industry.*